International Journal of Agricultural
Science and Research (IJASR)
ISSN(P): 2250-0057; ISSN(E): 2321-0087
Vol. 6, Issue 1, Feb 2016, 253-260

PERFORMANCE ASSESSMENT OF A SOLAR HOT WATER GENERATING SYSTEM WITH HEAT PIPE EVACUATED TUBE SOLAR COLLECTORS

A L JUDAL[1] & A G BHADANIA[2]

[1]*Research Scholar, Department of Dairy Engineering, SMC College of Dairy Science,*
Anand Agricultural University, Anand, Gujarat, India

[2]*Professor & Department of Head Dairy Engineering, SMC College of Dairy Science,*
Anand Agricultural University, Anand, Gujarat, India

ABSTRACT

The aim of this paper was to assess the performance of a solar hot water generating system with heat pipe evacuated tube collector (HP-ETC) during the months of October, November, December-2014 and January, February and March-2015. The experimental heat pipe evacuated tube collectors having 147 m^2 areas were used for the collection of solar radiation. The statistical analysis revealed that there is significant effect of month of operation and operating time on intensity of solar radiation of HP-ETC. The highest value of intensity of solar radiation of HP-ETC obtained during experimental months was 961 W/m^2 in the month of March, 2015. The interaction effect of month and time was also found significant. The maximum recorded HP-ETC outlet fluid temperature was 99.05 °C. The highest efficiency value of HP-ETC obtained during experimental months was 80.25 in the month of March, 2015. The interaction effect of month and time for efficiency of HP-ETC was found significant. It was found that efficiency of HP-ETC varies throughout the day depending on the intensity of solar radiation.

KEYWORDS: Solar Hot Water Generating System, Heat Pipe Evacuated Tube Collector, Intensity of Solar Radiation, Efficiency of HP-ETC

Received: Jan 29, 2016; **Accepted:** Feb 04, 2016; **Published:** Feb 09, 2016; **Paper Id.:** IJASRFEB201637

Original Article

INTRODUCTION

Solar energy is gaining popularity because it increases energy independence and sustainability leaving no negative impact on the environment, it can be a good alternative to solve the problem of the depletion of fossil fuels. There are many types of the solar collector such as flat-plate collectors, stationary compound parabolic collectors and evacuated solar collectors. Among them, since conventional simple flat-plate solar collectors were developed for use in sunny and warm climates, their performance are greatly reduced when conditions become unfavorable during cold, cloudy, and windy days. However, heat evacuated tube solar collectors (HP-ETC) use a vacuum-sealed tube which reduces convection and conduction losses, so the HP-ETC can operate at higher temperatures than flat-plate collectors. So many studies about efficiency of old version solar collector have been carried out (Morrison *et al.*, 2004; Zambolin and DelCol, 2010).

Evacuated solar collectors use liquid-vapor phase change materials to transfer heat at high efficiency. These collectors feature a heat pipe (a highly efficient thermal conductor) placed inside a vacuum-sealed tube. The heat pipe contains a small amount of fluid that undergoes an evaporating-condensing cycle. In this cycle, solar heat evaporates the liquid and the vapor travels to the heat sink region, where it condenses and releases its latent

heat. The condensed fluid returns to the solar collector and the process is repeated (Kalogirou, 2004). The use of HP-ETC in solar water heating systems (SWHS) is increasing worldwide because of their high thermal efficiencies and operating water temperatures when compared to flat plate collectors (FPCs). However, the on-site thermal performance of SWHSs with evacuated tube collectors has not been well evaluated and is therefore not well known to users (Chow *et al.*, 2011).

The literature review revealed that very scanty work in the area of using solar energy for evaluating the thermal performance of solar hot water generating system with HP-ETC both experimentally and theoretically has been reported. The development of new version of solar water heating system and design up-gradation of various components have made it feasible to use solar energy in vapour absorption plant using LiBr as absorbent and water as refrigerant. The information generated in the study would help not only to design the solar powered VAR system, but also provides basic know-how to evaluate the performance of the plant.

EXPERIMENTAL SET UP

The experimental heat pipe evacuated tube collectors having 147 m^2 areas were used for the collection of solar radiation. The stationary type solar thermal collectors array consists of 5 loops each comprising 9 collector modules. Each collector consists of 20 heat pipes immersed in evacuated tubes of 58 mm diameter and 1.5 m length. The condensing ends of all the 20 heat pipes are connected by a header. These evacuated tube collectors with heat pipe offers an unique advantage of raising temperature of the hot water to 80-90°C. The HP-ETC is shown in Figure 1. and technical specifications of HP-ETC are given in Table 1.

HOT WATER TANK

The hot water is generated in the heat pipe evacuated tube solar collector and it is stored in the insulated hot water storage tank which is shown in Figure 2. The hot water from hot water storage tank is supplied to the generator to boil off water vapor from the solution of Lithium bromide-water. The hot water storage tank mounted on MS frame has capacity of 1500 lit. The tank is fabricated from 8mm thick mild steel and it is insulated with 100mm thick rock wool having thermal conductivity value of around 0.55 W/m K at 100ºC.

METHODOLOGY

The performance of heat pipe evacuated tube collectors was evaluated in terms of efficiency (%) in the month of October, November, December- 2014 and January, February and March- 2015.

Performance Evaluation of Solar Hot Water Generating System

The heat pipe evacuated tube solar collectors (HP-ETC) are used for generation of hot water. The performance of solar hot water generating system was measured at the interval of 30 minutes from 9:00 to 17:00 hours in the month of October, November, December- 2014 and January, February and March- 2015 and values of efficiency of solar hot water generating system were calculated.

Efficiency of Heat Pipe Evacuated Tube Collector (Hp-ETC)

The quantity of heat transferred to the water is calculated by measuring water flow rate and temperature of inlet and outlet from solar array.

$$\therefore Q_W = m_w C_{pw} \left(T_{ow-T_{iw}}\right)$$

Where,

Q_W = Quantity of heat transferred to the water in the tank (kg/h)

m_w = Water flow rate (kg/h)

C_{pw}= Specific heat of water (kJ/kg. K)

T_{ow} = Water outlet temperature (°C)

T_{iw} = Water inlet temperature (°C)

The solar collector efficiency (η) can be expressed as a ratio of the amount of heat collected in the tank to the total amount of solar irradiation falling on the collector (Rittidech and Wannapakne, 2007; Kim, 2012).

$$\therefore \text{Efficiency of HP-ETC } (\eta) = \frac{Q_W}{A_C G_T} = \frac{m_w C_{pw} (T_{ow} - T_{iw})}{A_C G_T}$$

Where,

A_C= Solar collecting area (m^2)

G_T= Solar radiation (W/m^2)

RESULTS AND DISCUSSIONS

Effect of Operating Month and Time on Intensity of Solar Radiation of HP-ETC

The statistical analysis revealed that there is significant effect of month of operation and operating time on intensity of solar radiation of HP-ETC. The highest value of intensity of solar radiation of HP-ETC obtained during experimental months was 961 W/m^2 (M_6T_{10}) in the month of March, 2015. The interaction effect of month and time was also found significant. The month wise average solar radiation on the surface of HP-ETC is depicted in Figure 3.

Effect of Operating Month and Time on Efficiency of HP-ETC

The statistical analysis revealed that there is significant effect of month of operation and operating time on intensity of solar radiation of HP-ETC. The highest value of intensity of solar radiation of HP-ETC obtained during experimental months was 84 % (M_6T_9) in the month of March, 2015. The interaction effect of month and time was also found significant. The month wise average solar radiation on the surface of HP-ETC is depicted in Figure 4.

CONCLUSIONS

The following conclusions have been derived from the study:

- The average solar intensity ranged from 95.67 to 683.47 W/m^2, 97.24 to 692.03 W/m^2, 100.30 to 756.60 W/m^2, 116.16 to 816.80 W/m^2, 150.55 to 937.70 W/m^2 and 221.49 and 961.57 W/m^2 during 9:00 to 17:00 h in the month of October, November, December-2014 and January, February and March-2015 respectively. The statistical analysis revealed that there is significant effect of month of operation and operating time on intensity of solar radiation of HP-ETC. The highest value of intensity of solar radiation of HP-ETC obtained during experimental months was 961 W/m^2 in the month of March, 2015. The interaction effect of month and time was also found

significant.

- The intensity of solar radiation increased from morning to about 13:30 p.m. and subsequently it reduced in afternoon period. The trend of variation of intensity of solar radiation was almost similar during all other months of study period.
- The regression equations obtained correlating solar intensity and time were $y= -35.05x^2 + 907.1x – 5166$ ($R^2 = 0.968$), $y= -32.71x^2 + 839.9x – 4668$ ($R^2 = 0.966$), $y= 2.173x^3 - 119.6x^2 + 1960x – 9301$ ($R^2 = 0.986$), $y= -38.56x^2 + 991.8x - 5594$ ($R^2 = 0.969$), $y= -40.56x^2 + 1034x – 5693$ ($R^2 = 0.972$) and $y = 0.795x^3 - 69.01x^2 + 1346x – 6635$ ($R^2 = 0.988$) for month of October, November, December-2014 and January, February and March-2015 respectively.
- The variation in solar intensity was more in the month of March, 2015 as compared to previous five months. The regression equations obtained correlating time with intensity (W/m^2) are useful to predict intensity of solar radiation during the whole day. The temperature of hot water generated in HP-ETC depends on the intensity of solar radiation.
- The efficiency of HP-ETC ranged from 24.57 to 55.44 %, 25.22 to 59.00 %, 29.35 to 61.13 %, 31.58 to 66.91 %, 35.12 to 70.33 % and 44.84 to 80.25 % in the respective months of the study periods. The non-tracking type stationary HP-ETC can produce hot water temperature required for the generator of the SVAR system. There is significant effect of month of operation and operating time on the efficiency of HP-ETC. The highest efficiency value of HP-ETC obtained during experimental months was 80.25 in the month of March, 2015. The interaction effect of month and time was also found significant. It was found that efficiency of HP-ETC varies throughout the day depending on the intensity of solar radiation. The efficiency of HP-ETC was maximum at about 13:30 pm during all the months of the study period.
- The regression equations obtained correlating efficiency (%) of HP-ETC with time of the day were $y= -0.019x^6 + 1.465x^5 - 46.52x^4 + 779.2x^3 - 7262x^2 + 35725x – 72475$ ($R^2 = 0.984$), $y= -1.806x^2 + 46.31x - 241.5$ ($R^2 = 0.953$), $y= 0.053x^4 - 2.871x^3 + 55.09x^2 - 447.4x + 1339$ ($R^2 = 0.950$), $y=-0.020x^6 + 1.569x^5 - 50.02x^4 + 841.1x^3 - 7870x^2 + 38865x – 79142$ ($R^2 = 0.970$), $y=-0.015x^6 + 1.170x^5 - 37.38x^4 + 629.3x^3 - 5890x^2 + 29074x – 59135$ ($R^2 = 0.974$) and $y=0.213x^4 - 11.13x^3 + 212.0x^2 - 1745x + 5299$ ($R^2 = 0.958$) during operation of HP-ETC in the respective month of experimental study. These regression equations obtained correlating efficiency of HP-ETC and time are quite useful to predict the thermal energy generated from HP-ETC.
- The values of outlet temperatures of water from solar array ranged from 68.23 to 87.24 ^oC, 69.52 to 90.50 ^oC, 73.67 to 97.33 ℃, 72.28 to 97.86^oC, 73.50 to 97.98 ^oC and 72.92 to 99.05 ^oC during the respective months of study period. It was also noticed that the temperature of water from solar array was increased from morning to noon and subsequently it decreased in afternoon time. The LiBr-water SVAR system can be operated using hot water at temperature ranging from 65-95 ˚C by maintaining about 6 mm of mercury pressure in the shell of evaporator. It is revealed that there is significant effect of month of operation and operating time on outlet temperatures of water from solar array. The highest value of outlet temperatures of water from solar array obtained during experimental months was 99.05 °C in the month of March, 2015.

REFERENCES

1. *Ammar M. A., Saeed A. Y., Hamda A. T., 2013. Design and performance evaluation of a photovoltaic grid-connected system in hot weather conditions, Renewable Energy, **53**(1), 71-78.*
2. *Ayompe L. M., Duffy A., 2013 Thermal performance analysis of a solar water heating system with heat pipe evacuated tube collector using data from a field trial, Solar Energy, **90**, 17-28.*
3. *Ayompe L. M., Duffy A., Mc Keever M., Conlon M., McCormack S. J., 2011. Comparative field performance study of flat plate and heat pipe evacuated tube collectors (ETCs) for domestic water heating systems in a temperate climate. Energy, **36**, 3370-3378.*
4. *Chow, T. T., Dong, Z., Chan, L. S., Fong, K. F., BAI, Y., 2011. Performance evaluation of evacuated tube solar domestic hot water systems in Hong Kong. Energy and Buildings **43**, 3467-3474.*
5. *Kalogirou, S. A., 2004. Solar thermal collectors and applications. Progress in Energy and Combustion Science. **30,** 231-295.*
6. *Kim J. S., Ha S. J., Lee S. and Jeong B. H. (2012) The study of evacuated solar collector using pulsating heat pipe. Frontiers in heat pipes (FHP), **3**: 1-5.*
7. *Morrison, G. L., Budihardjo, I., Behnia, M., 2004. Water-in-glass evacuated tube solar water heaters. Solar Energy, **76,** 135-140.*
8. *Narayan J., Yadav Y. P., 2007. Metallic condensing surface solar still augmented by asymmetric CPC, Proceeding of 3rd International conference on solar radiation and day lightning New Delhi, Anamaya Publishers, New Delhi, India, pp-130-135.*
9. *Rittidech S., Donmaung A., Kumsombut K. (2009) Experimental study of the performance of a circular tube solar collector with closed-loop oscillating heat-pipe with check valve (CLOHP/CV), Renewable Energy, **34**: 2234–2238.*
10. *Singh S. K., Prasad A. S., 2007. Analytical study of single Basin solar still with coil type heat exchanger, Proceeding of 3rd International conference on solar radiation and day lightning New Delhi, Anamaya Publishers, New Delhi, India, pp-32-38.*
11. *Solanki C. S., 2010. Solar PV Electricity Solutions for Academic Campuses in India, Dept. of Energy Science and Engineering, IIT Bombay. pp :6-7*
12. *USDA., 2001. Forecasting heat stress cited on 15th April, 2015, (http://www.ars.usda.gov/Main/docs.htm?docid=15616&pf=1&cg_id=0)*
13. *Zambolin, E., Del Col, D., 2010. Experimental analysis of thermal performance of flat plate and evacuated tube solar collectors in stationary standard and daily conditions. Solar Energy, **84**, 1382-1396.*

APPENDICES

Figure 1: Heat Pipe Evacuated Tube Collector (HP-ETC)

Table 1: Technical Specifications of HP-ETC

Water Flow Rate	**3.2 -5.5 m^3/h**
Glass material	Borosilicate glass
Absorptive coating	ALN/AIN-SS/CU
Absorption co-efficient	>92%
Emission co-efficient	<8%
Stagnation temperature	>220°C
Outlet diameter of glass tube	58 mm
Inner diameter of glass tube	47 mm
Length of glass tube	1800 mm
Thickness of glass tube material	1.6 mm
Manifold (Header)	Copper with rock wool insulation
Frame material	Stainless steel AISI 304

Figure 2: Hot Water Storage Tank

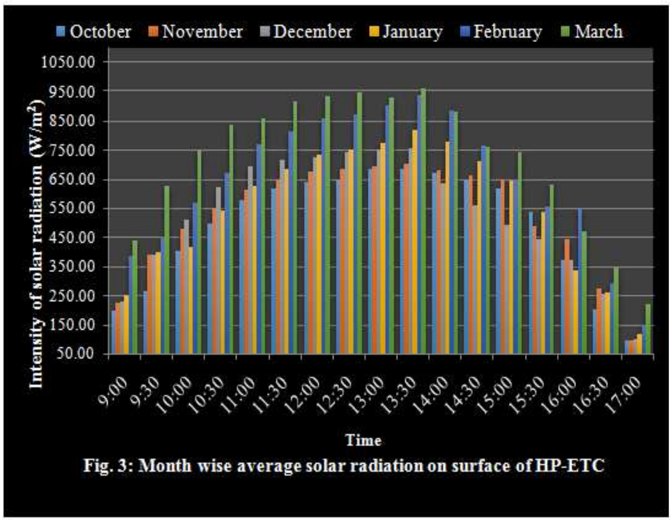

Figure 3: Month Wise Average Intensity of Solar Radiation

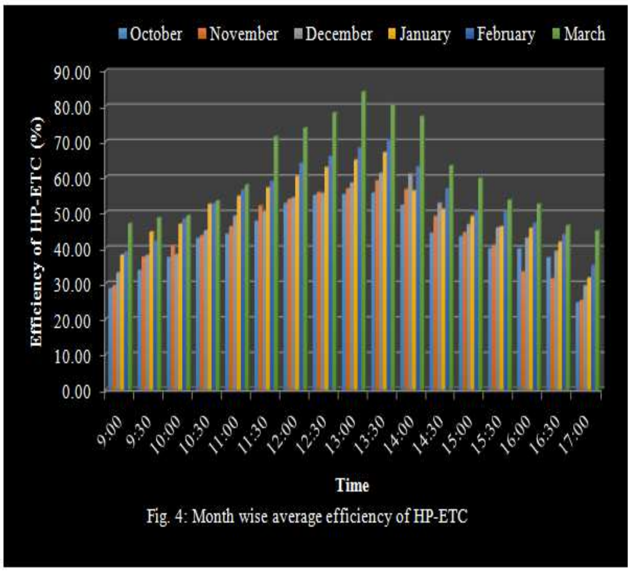

Figure 4: Month Wise Average Efficiency of HP-ETC